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RESEARCH ARTICLE

Effects of Filler Content and Compatibilizers on the Properties of Low-Density Polyethylene (LDPE)/Thermoplastic Potato Starch (TPS) Blend Composite

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ABSTRACT: In this study, potato starch (PS) was physically mixed with low-density polyethylene (LDPE) through twin screw extruder to form LDPE/PS composites. Glycerol was added to the mixture as a plasticizer to increase the compatibility of PS and LDPE, which subsequently reduced the brittleness of the composite. The effect of thermoplastic potato starch (TPS) content and two different compatibilizers on the melt flow index (MFI), mechanical properties, morphology, thermal properties, and biodegradability of LDPE/TPS composites were investigated. The results show that the MFI of LDPE/TPS composite with or without compatibilizer decreased as the content of TPS increased. The mechanical properties such as tensile modulus, flexural strength, and modulus of the uncompatibilized composites begin to increase, but the tensile strength and impact strength gradually decrease as the TPS content increases. The addition of compatibilizer further enhances the mechanical properties of the composite. Morphological observations have shown that compatibilized composites can form a good bond between TPS and LDPE, and that starch particles are evenly dispersed in the polymer matrix. In addition, DSC, thermal stability, and biodegradability were performed for dissimilar LDPE/TPS composites. Besides, water absorption of LDPE/TPS composites was reduced through the addition of compatibilizers.

KEYWORDS: Potato starch, LDPE, compatibilizers, mechanical testing, morphology, thermal properties

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INTRODUCTION

Plastic is an ordinary organic polymer made from petrochemicals, which is formed and used universally. This simplifies their processing, low energy consumption during production, and inertia, which makes them suitable for use in all cases [1]. The most widely used synthetic polymers are polythene because they are highly hydrophobic and have high molecular weight. In particular, low-density polythene (LDPE) is the most widely used polythene grade, combined with competitive market prices due to its relatively good mechanical properties. Nevertheless, the ever-increasing production and rapid expansion in the use of plastic ingredients have created an extraordinary problem in the management of plastic waste disposal.Plastics are naturally soluble for microorganisms or chemicals in the environment [2]. Therefore, the disposal of high-volume plastics, which take a long time to decay, reasons enormous ecological problems [3]. To address the ecological harms related to traditional plastics, many efforts have been made in recent years to develop biodegradable materials. These ingredients can be synthetic, natural, or a combination of both. To provide the degradability of polymers, modified plastics obtained from blending with agricultural feedstock, for example, starch offer an elegant approach to meet starch requirements and use the ecosystem of the resource and ensure at least partial decay [4].

Starch is considered to be the most promising natural polymer available for the development of biodegradable substances due to its low cost, abundant availability and attractive combination of properties such as

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thermoplastic behavior [3]. Potatoes are one of the world's leading sources of starch. Starch comprises two different polysaccharide structures, linear amylose, and the high branched amylopectin. And, the intermolecular and intramolecular hydrogen bonds within the hydroxyl group of starch molecules lead to crystallinity in native starch [5]. In the existence of plasticizers like glycerol, it can perform like a thermoplastic ingredient at high temperatures and under the shear, they can easily melt and flow, allowing them to be used as an extruded or injected ingredient like most traditional synthetic thermoplastic polymers [6]. In our previous works, it was found that high amounts of starch could be added to LDPE in the form of thermoplastic (plasticized) and when using so-called thermoplastic starch (TS) [7,8].The main sources of starch usually used for the creation of biodegradable polymers are potatoes, sago, maize, tapioca, and rice [9]. However, very few reports have been received about the properties of potato starch mixture.Bangladesh is one of the potato-growing countries. Excess production compared to the current demand for the development of degradable material makes potato starch attractive and promising filler for polyethylene.However, it has been found that adding TS as a minor phase to the synthetic thermoplastic matrix reduces the mechanical properties as a major phase [10]. The hydrophilic nature of the starch and the hydrophobic nature of the polymer as well as the inconsistencies arising from the water absorption tendency of the starch reduce the mechanical performance of the mixture [11]. However, these problems can be improved using a compatibilizer that can react with the hydroxyl group of starch and form hydrogen bonds or covalent bonds with synthetic polymers.Until today, considerable research has been done to increase compatibility, such as the modification of starch [12,13], the modification of polyethylene [14,15], and the introduction of compatibilizers [16,17] into mixtures of starch and polyethylene.

Many studies have shown that mixtures of starch and polythene are not biodegradable in realistic time frames, but they do come into contact with the soil environment and cause biodegradation. Investigational evidence indicates that only surface starch is biodegradable, which leaves an irresistible polyethylene ingredient. It has been recommended that olefin-based polymers with working groups such as carboxylic acids, anhydrides, an epoxy can form a variety of polymers, including starch [18,19]. Maleic anhydride (MA) is one of the most broadly used vinyl monomers for poly-olefin graft modification [20] because high polar MA is the main suitable working group for starch. Dibutyl maleate (DM) has been selected due to its low volatility and low toxicity compared to MA. To date, many researchers have worked to improve the compatibility of starch modifications, such as combinations of starch and polyethylene [21-23]. However, there is some evidence in research on the use and compatibility of MA and DM in starch-filled LDPE. The main objective of the present work is to examine the effect of filler concentration and compatibilizers on the physical properties, morphological structure, thermal and biodegradable properties of LDPE/thermoplastic potato starch (TPS) composites.

EXPERIMENTAL

Materials

LDPE extrusion film grade LD1902F was procured from Cementhai Co., Ltd. (Thailand) and was used as a polymer matrix. Its melt flow index (MFI) and density reported by the manufacturer were 2.0g/10 min and 0.919 g/cm^3, respectively. Food grade potato starch (10% moisture) obtained from S.D. Fine Chemicals Limited, Mumbai, India. Maleic anhydride obtained from S.D. Fine Chemicals Limited, Mumbai, India was used as a compatibilizer, and dibutyl maleate compatibilizer was laboratory reagent grade. Dicumyl peroxide (DCP) was obtained from Sigma Aldrich Chemicals Pvt Ltd., India, which was used as an initiator. Glycerol (glycerine, C3H8O3) (molecular weight = 92gmol^{-1}) from Fisher Chemicals was used as a plasticizer.

METHODS

Preparation of Thermoplastic Potato starch (TPS)

Glycerol and distilled water were mixed for 10 min. A mixture of distilled water and glycerol was added to the potato starch and stirred until homogeneous. Aging was administered for 2 days in a mixture of distilled water and glycerol may be completely absorbed in the raw material which in turn may have a positive effect on thermoplastic starch. Mixing was done using Rheomix for 15 min and Rheomix at barrel at 90-90-90^{o}C. The screw speed was maintained at

60 rpm. Samples of Rheomix were resized using a blender/grinder.

Preparation of LDPE/TPS Composites

Blending was carried out using a twin-screw extruder (Model: TSE 20, GmbH & Co. KG, Germany). LDPE was first added to the mixing chamber and then applied 3 minutes after mixing TPS, MA or DM, and DCP. Mixing was done from the mixing feeder at 160°C-160°C-150°C-150°C and 70 rpm for 10 min [24]. TPS content was varied from 10 to 30 by weight of LDPE. The composites were made with four dissimilar weight percentages of TPS and the amount of LDPE with or without compatibilizer. MA or DM and DCP were used as monomer and initiator at 3 and 0.2 wt% levels based on LDPE, respectively. The detailed compositions of samples are listed in Table 1. The extruded components were cooled and then palletized by a pelletizer. The resultant blend was then molded using injection molding (Toyo, model: Si180iii-E200, Japan). The barrel temperature and clamps for each blend and their combination were similarly fixed at 180°C and 180T.

MFI Measurement

The melt flow index (MFI) of several samples was measured using an extrusion plastometer by ASTM D1238-01. The measurements used a load of 2.16 kg and a temperature of 180°C.

Mechanical Tests

Tensile properties such as tensile strength (TS) and tensile modulus (TM) were measured by using Tinius Olsen H10KL (Column Digital Universal Testing Machine) equipped with 5 KN load cells by ASTM-D 638-03 standards [25]. Five samples measuring 165 × 13 × 3 mm3 were tested in each case, and the cross-head speed was set to 10 mm/min. Flexural testing (three-point curvature) for the composite was performed by the ASTM D 790-01 standard [26]. The dimensions of the sample used were 125 mm × 12.5 mm × 3 mm using the same testing machine mentioned above at the same crosshead speed. According to ASTM-D 256 standards, the notched Izod impact strength (IS) was measured using an impact machine (model, Toyo Seiki Co., Japan). The dimensions of the sample were 63.5 × 12.7 × 3 mm^3. All tests were performed at room temperature (25± 2°C) and relative humidity was measured at 55 ± 5%. Five replicated samples of each composition were individually tested for the property.

Morphological Analysis

Scanning Electron Microscopy (SEM) was used to examine the changes in surface morphology and mode failure of LDPE/TPS blends. The samples were coated with gold to prevent electrical discharge during the test. The LDPE/TPS mixtures were immersed in liquid nitrogen to break them down and test them under the broken surface.

Thermal Properties

Differential scanning calorimeters (Perkin Elmer DSC7) and a thermogravimetric analyzer (Perkin Elmer TGA7) were employed to detect the thermal properties of LDPE/TPS composites. For the DSC study, 8 to 10 mg samples, encapsulated in a hermetically sealed aluminum pan, were arranged. The sample was heated from 25°C to 190°C, then the sample was cooled to 25°C and finally reheated to 190□C at a scanning rate of 10°C/min for each test. The melting temperature (Tm) and the heat of fusion (ΔHf*) of the sample were determined from the maximum peak and the area under the peak, respectively. The degree of crystallinity of the LDPE/TPS composite and LDPE phase was calculated using the following equation:

$$\%\ \text{crystallinity} = \frac{\Delta H_f^*}{\Delta H_f^0} \times 100 \qquad \text{----(1)}$$

where ΔH_f^* is the heat of fusion of the semicrystalline LDPE blends and ΔH_f^o is the heat of fusion for 100% crystalline LDPE.

The thermal gravimetric analysis (TGA) of samples was carried out on a TA apparatus (New Castle, DE), type TGA Q500thermal analyzer. The sample is heated from 30°C to 600°C at a heating rate of 10°C/min and a nitrogen gas flow rate of 40 ml/min.

Biodegradability Test

The biological enhancement of the sample was determined using weight loss over time in the soil environment. Blend samples measuring 25 × 25 × 3.0 mm^3 were dried and weighed to obtain a dry weight. These specimens were then buried 20 cm below the surface of the alluvial soil and placed in the perforated box which was moistened with regular water. After several time intervals, the samples are carefully removed from the soil and quietly refined with pure water to adhere to the soil perimeter. The samples were dried at a temperature of 70°C under a vacuum oven until a certain weight was reached. The resulting weight loss percentage is calculated using the equation:

$$\text{Weight loss}\,(\%) = \frac{W_2 - W_3}{W_2} \times 100 \qquad \text{----(2)}$$

Where, W2 is the initial weight (i.e., weight before degradation) and W3 is the final weight (i.e., weight after degradation).

Water Absorption Test

Before testing, virgin LDPE and composite samples (7×2 cm2) were dried in a vacuum oven at 80°C for 5 h to remove the amount of water. The samples were then completely immersed in pure water for 30 days. After this period of immersion, the samples were separated at regular intervals, and surface water was wiped with tissue paper, and weighed using analytical equilibrium with a resolution of 0.1 mg.

RESULTS AND DISCUSSION

Melt Flow Index Measurement

MFI values for virgin LDPE, uncompatibilized, and compatibilized composites are presented in Table 1. It was found that the MFI of virgin LDPE was higher than that of the uncompatibilized composites. It can be seen that the MFI of the LDPE/TPS composite has decreased as the amount of starch has increased. The value of MFI decreases as the viscosity of the composite increases. MFI has reduced because starch particles are more viscous than LDPE. However, the reduction of MFI became more balanced with the inclusion of MA or DM. MA or DM reduces the intermolecular force in the polymer coil and increases the molecular space [27] and increases the MFI as a result of polymer motility. In higher filler materials, the composite melt flow is disrupted and the amount of composite flow resistance is further increased, which contributes to the smaller MFI of the composite. It was found that LDPE/TPS composites with MA or DM showed higher MFI than composites without MA or DM. MA or DM inclusions reduce the viscosity of composites in LPTS and develop their fluidity. Compatibilizers have improved the interface bond between the matrix and the filler, which has higher flow properties for composite melting. MA or DM treated composites showed lower viscosity which would suggest processing steps.

Table 1. Compositions and MFI of LDPE/TPS composites with and without compatibilizer

Samples	LDPE (wt.%)	Starch (wt.%)	MA(wt.%)	DM(wt.%)	DCP(wt.%)	MFI (g/10min)
LDPE	100	0	–	–	–	2.87±0.31
Uncompatibilized						
LTPS10	90	10	–	–	–	2.39±0.22
LTPS15	85	15	–	–	–	2.27±0.14
LTPS20	80	20	–	–	–	2.19±0.12
LTPS30	70	30	–	–	–	1.96±0.11
Compatibilized						
LTPS10M	90	10	3	–	0.2	2.58 ± 0.12
LTPS15M	85	15	3	–	0.2	2.45 ± 0.10
LTPS20M	80	20	3	–	0.2	2.36 ± 0.22
LTPS30M	70	30	3	–	0.2	2.31 ± 0.21
LTPS10D	90	10	–	3	0.2	2.71 ± 0.24
LTPS15D	85	15	–	3	0.2	2.58 ± 0.29
LTPS20D	80	20	–	3	0.2	2.51 ± 0.19
LTPS30D	70	30	–	3	0.2	2.43 ± 0.16

LPTS: LDPE/TPS

Evaluation of Mechanical Properties

Tensile Properties

The variation in the tensile properties (tensile strength and tensile modulus) of uncompatibilized and compatibilized LDPE/TPS composites as a function of TPS content (10%, 15%, 20%, and 30%) is shown in Figure 1(a) and 1(b), respectively. As observed from Figure

1(a), the tensile strength was decreased with increasing TPS content, regardless of the existence of MA or DM. This common phenomenon is due to the presence of starch particles, which do not contribute to the mechanical properties of the mixture and have been observed in many studies [28, 29]. As is well known, the starch granule is highly hydrophilic, with a hydroxyl group on the surface, whereas LDPE is essentially non-polar. Thus, it is not possible to form strong interfacial bonds like hydrogen bonds. Consequently, when stress was applied to the mixtures, fracture resistance of the mixtures without adding MA or DM did not improve. However, the main objective was to examine the effect of MA or DM on the mechanical properties of the LDPE/TPS mixture. Adding MA or DM has markedly strengthened TPS and LDPE interfacial additions. This increased interfacial adhesion to the mixture was thought to be responsible for the chemical reaction of the MA or DM group with the hydroxyl group with the starch at the interface. According to Hwang et al. [30], the addition of a compatibilizer can improve the crystallization which in turn increases the tensile strength of the mixture. The polar carboxyl groups of the side chains of the grafted PE are compatible with magnesium hydroxide (MH), whereas the main chains of the grafted polymer are well compatible with LDPE, and thus improve the adhesion between MH and LDPE [31].

Figure 1(b) shows the effect of TPS content on tensile modulus for virgin LDPE and LDPE/TPS composites with or without MA or DM. The results can be seen in Figure 1(b), where it can be observed that the TPS content up to 30 wt% has a significant effect on the tensile modulus. The reason for the modulus increase in composites is that starch particles are harder than distributors in LDPE [32]. Another reason for the higher modulus is that the starch particles did not melt enough and kept their shape as hard filler during processing. Since starch is partially crystalline, the addition of crystalline starch to the LDPE/TPS mixture increases the modulus as the starch content increases [23]. The addition of compatibilizers to LDPE/TPS composites shows a higher modulus than uncompatibilized LDPE/TPS composites. This result may be due to the compatibility effect of MA or DM on the composites, which promotes a higher interfacial bond between the filler and the matrix where the fillers strengthen the composite material.

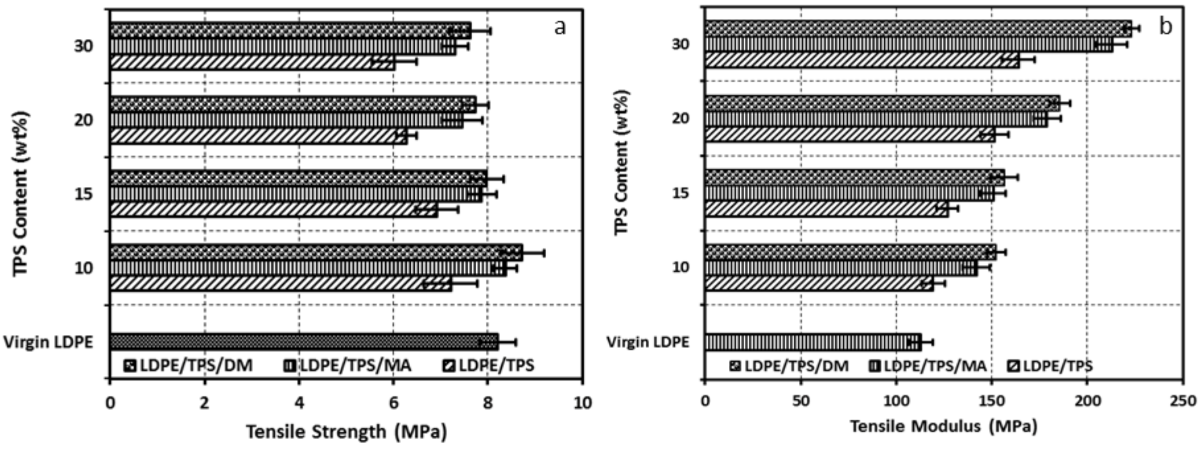
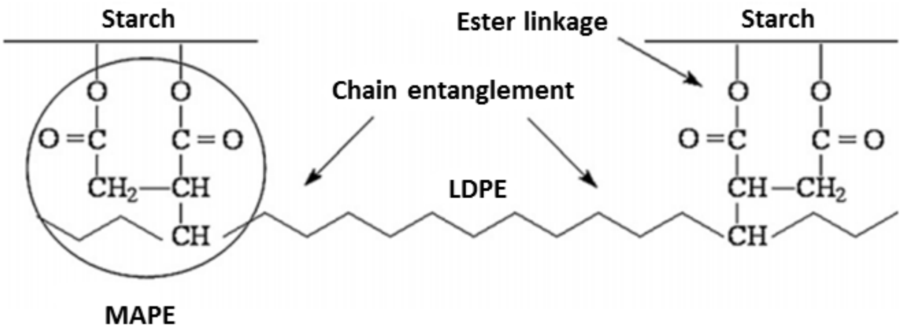
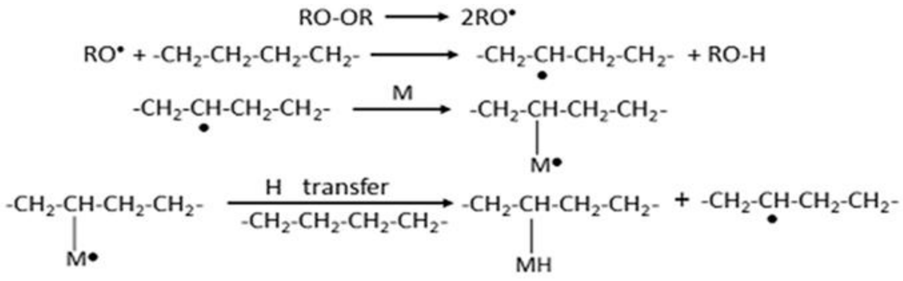


Figure 1Compatibilizing effect on the (a) tensile strength and (b) tensile modulus of LDPE/TPS composites

The tensile properties are improved due to the attachment of a chain between the PE parts between the LDPE and MA molecules as presented in Scheme1. The feedback promotes strong adherence between the filler and the matrix interface, thus enhancing the filler-matrix interaction resulting in higher tensile strength [33].Using the DM compatibilizer, the enhancement of the tensile properties to increase the attachment between the LDPE and starch layers through the compatibilizer may be recognized. The reactive process of grafted DM in LDPE is presented in scheme 2. Comparison between LDPE/TPS samples added to MA or DM compatibilizer has shown that the use of DM leads to greater mechanical properties of LDPE/TPS samples than MA compatibilizer users.



Scheme 1 Starch interface with MAPE and LDPE



Notes: RO-OR: DCP; $-CH_2-CH_2-CH_2-CH_2-$: LDPE; M: DM

Scheme 2. The reactive mechanism of DM was grafted in LDPE

Flexural Properties

Figures 2(a) and 2(b) show the effect of TPS content on flexural strength and flexural modulus for uncompatibilized and compatibilized composites. As can be seen from Figure 2(a), the flexural strength increased with an increasing amount of TPS for all samples. In the same percentage of TPS content, compatibilized composites exhibited higher flexural strength than Uncompatibilized composites. For uncompatibilized composites, maximum flexural strength was observed at 20.9 MPa and minimum at 16.7 MPa for 30% and 10% TPS content, respectively. However, LDPE/TPS composites with MA or DM with the same TPS content show higher flexibility than LDPE/TPS composites without MA or DM. This is probably due to the higher interfacial bond between the filler and the matrix after the chemical treatment.

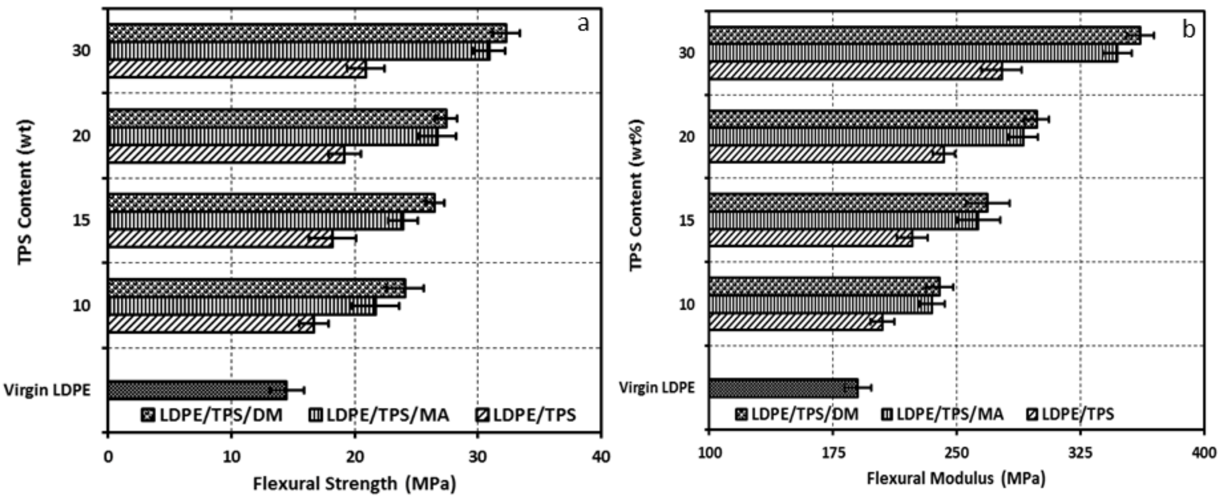


Figure 2Compatibilizing effect on the (a) flexural strength and (b) modulus of LDPE/TPS composites

Figure 2(b) shows the flexural modulus of LDPE/TPS composites for uncompatibilized and compatibilized composites with several TPS contents. As the TPS content increased by 30 wt%, the flexible modulus increased by about 46% compared to virgin LDPE. Chain entanglement between LDPE and polyethylene parts of MAPE molecule as presented in Scheme 1 may lead to improvement of flexible properties. Also, a strong ester linkage may be formed between the MA or DM portion of MAPE/DM and the hydrophilic potato starch, so that the incompatible portion between the hydrophilic potato starch and the hydrophobic LDPE may be attached and strengthened.

Impact Properties

Figure 3 shows a variation of impact strength with TPS content for uncompatibilized and compatibilized composites. It was started that impact strength showed a significant decrease with the increase in TPS content. The reduced impact strength has been recognized for uncompatibilized composites because TPS content further enhances the blending of bundles and provides poor adjustment in two stages. This reduction is responsible for changing the behavior of elastic to inelastic material. Also, a small increase in impact strength has been observed with the composite of compatibilizers. This seems to be sufficient for the increase in the impact strength of the compatibilized (LDPE/TPS with MA or DM) composite, as it increases to the formless phase characterized by the ability to push the effect. After the effects of the TPS increase suggested a reduction in impact strength, the filler-filler contact was more closed than the filler matrix contact. An additional possibility of low impact strength is that TPS melts during expansion and cannot retain its form as a strong filler [34]. The particle-matrix interaction decreases with the reduction of the particle aggregate and does not show the starch compound to harden but the fracture begins to fail.

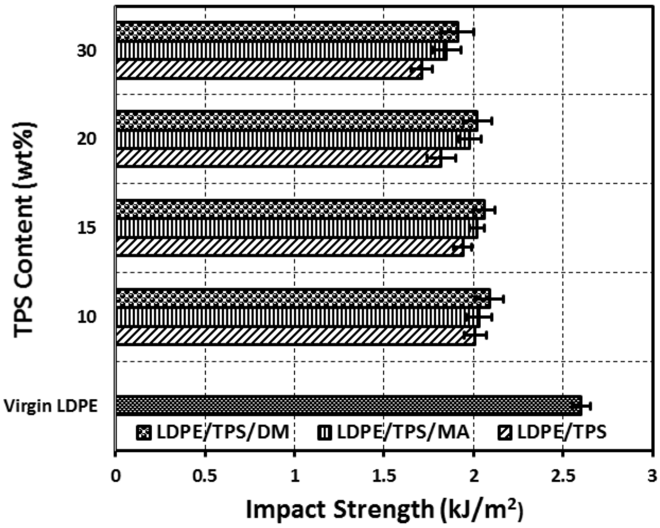


Figure 3 Compatibilizing effect on the impact strength of LPTS composites

Morphological Observation

The morphology of the LDPE/TPS (70:30) composite with and without compatibilizer was identified by SEM in the surface structure in Figure 4. Figure 4(a) displays that the composite is not well dispersed. It is found in surface structures of biodegradable plastics that show low uniformity and poor adhesion.It can be seen on the surface of biodegradable plastics that due to the difference in polarity between the two, starch does not mix with the high surface tension LDPE polymer.Pushpadass et al. [35] also expressed the view that the mixture between LDPE and corn starch results in non-homogeneous distribution of LDPE in the starch network.Due to the formation of hydrogen bonds and the wide characteristic differences between LDPE and starch, poor distribution of starch in LDPE occurs.

As shown in Figure 4(b), the LDPE/TPS/MA composite has good distribution and uniformity of starch in the matrix. Figure 6(b) also shows that a small amount of starch is covered by a certain amount of LDPE. Enhanced interfacial adhesion was attributed to chemical reactions between anhydride group and hydroxyl group potato starch and physiological interactions

Haydar U Zaman & Ruhul AKhan

between LDPE and MA under high temperature and high shear extrusion conditions. Figure 6(c) shows the fracture surface of the LDPE/TPS/DM composite showing that the starch particles are well dispersed in the matrix because no clear interface between starch and LDPE can be observed. This is due to the adherence of the given polymers across the bond between starch and LDPE growth. Extended bonds are based on improving the compatibility of grafted polymers with starch and LDPE. As shown above, there is a good bond between filler and matrix resulting in composite growth.

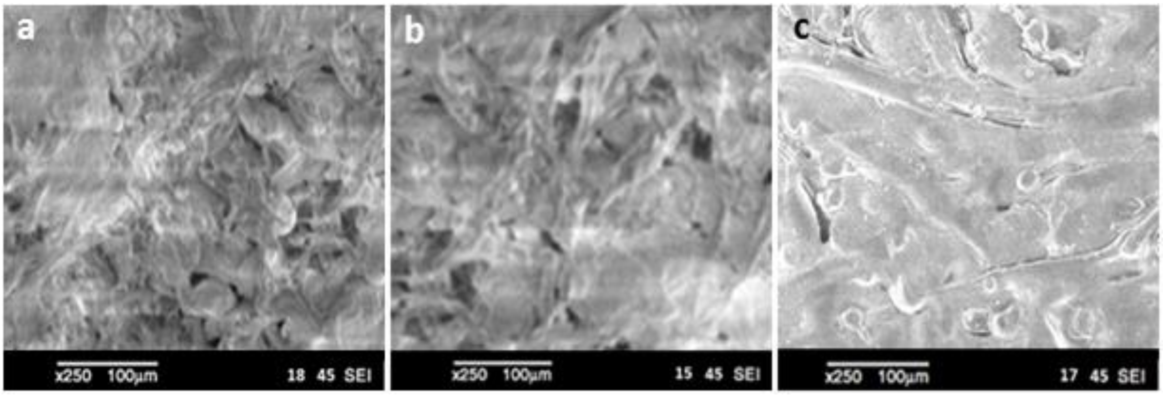


Figure 4 SEM photomicrographs on the fractured surface of (a) LDPE/TPS, (b) LDPE/TPS/MA, and (c) LDPE/TPS/DM composite

Thermal Analysis

Crystallization Behaviors

Figure 5 and Table 2 display the thermal graphs and thermal parameters of virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites. DSC endotherms exhibited very slight changes in the crystal size of the matrix, meaning that the melting temperature (T_m) was dependent on plasticizers and compatibilizers in the temperature range. T_m of virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites was between 131.85-138.87°C. Compared to virgin LDPE, T_m is transferred to higher temperatures of the composite, and maximum T_m is found in LDPE/TPS/DM composites. The hydroxyl group in glycerin formation can form hydrogen bonds with LDPE and starch. This is consistent with the increase in the tensile properties of the LDPE/TPS/MA or LDPE/TPS/DM composites mentioned in the previous section. Table 2 shows that the ΔH_f values of LDPE and LDPE/TPS were 102.75 and 106.89, respectively. The growth in ΔH_f is due to the creation of maleate ester groups from the interaction between the –OH group of starch and the maleate ester group of the dibutyl maleate. With the addition of compatibilizers, the percentage of crystallinity in the matrix has increased significantly. Crystallinity levels in LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites increased to 4, 15, and 23%, respectively. LDPE/TPS/DM composites showed higher crystallinity than LDPE/TPS/MA composites, and therefore the tensile and flexible properties of LDPE/TPS/MA composites were lower than those of LDPE/TPS/DM composites. The addition of compatibilizer to semicrystalline polymers increases the crystallization rate, resulting in higher crystallinity and higher ΔH_f[36].

Table 2. Thermal characteristics of LDPE/sago starch composites.

Samples (wt.%)	**T_m (ºC)**	**ΔH_f (J/g)**	**X_c (%)**
Virgin LDPE	131.85	102.75	37.68
LDPE/TPS	133.91	106.89	39.31
LDPE/TPS/MA	136.26	110.57	43.27
LDPE/TPS/DM	138.87	115.35	46.36

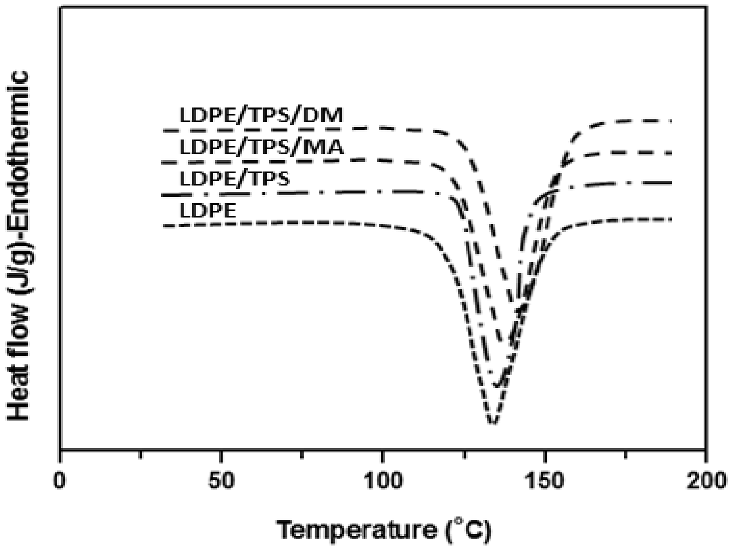


Figure 5 DSC diagrams for virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites

TGA Analysis

Onset degradation temperature (T_{onset}) and TGA diagrams for LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites are presented in Figure 6. It should be noted that the initial weight of LDPE/TPS decreased from about 300°C to 380°C, mainly due to the decomposition of TPS and the last shift to 452°C was due to heat dissipation of LDPE. The weight loss of the LDPE/TPS composite has been decreased with the addition of a compatibilizer. Adding compatibilizers increases the thermal stability of composites. It was found that the weight loss of virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites was 98.2, 95.7, 92.4, and 90.1%, respectively. It is believed that weight loss was the result of improved thermal stability. LDPE/TPS/DM composite weighed less than LDPE/TPS/MA composite. The good thermal stability of the LDPE/TPS/DM composite was recognized for good interfacial contact between the maleate ester group of DM and the -OH group of starch, thus improving the interfacial contact between TPS and LDPE.

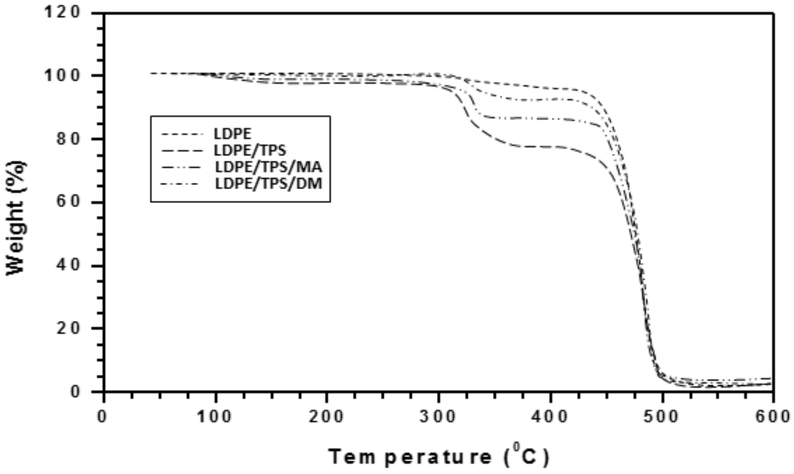


Figure 6 TGA thermogram of virgin LDPE and its composites

Soil Degradation

Figure 7 displays the deterioration of virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites in the soil. It is predictably, that the water existing in the soil breaks down into samples of the mixture, causing swelling and increasing the biological spread. Weight loss of LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites increases with increasing burial time. It suggests that fungi and bacteria exist in the soil environment as microorganisms, take up starch and make holes in the polymer matrix. Weight loss gradually increases with increasing burial time and after 6 months of study the weight loss of LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites was 6.91, 4.66, and 3.41%, respectively. The low weight loss of LDPE/TPS/DM composite may be associated with improved interfacial bonding between LDPE and TPS and other similar factors that lead to water uptake. Higher biodegradation of LDPE/TPS composite may be due to the same factors as higher water absorption and lower mechanical properties.

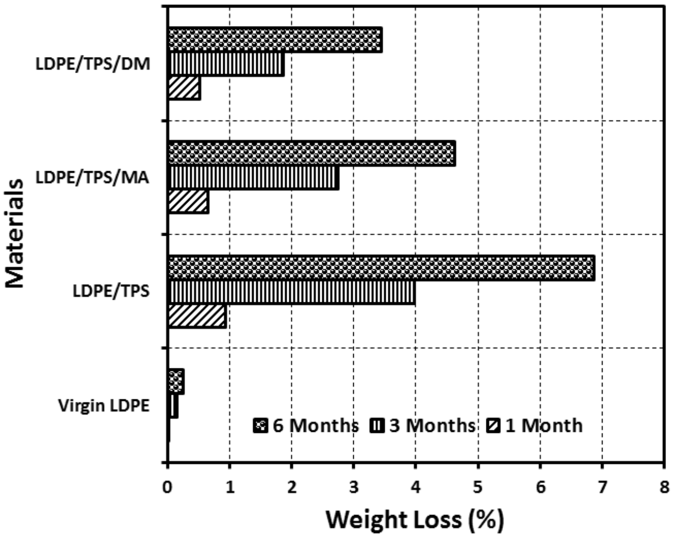


Figure 7. Burial time vs. weight loss of virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites exposure to the soil environment.

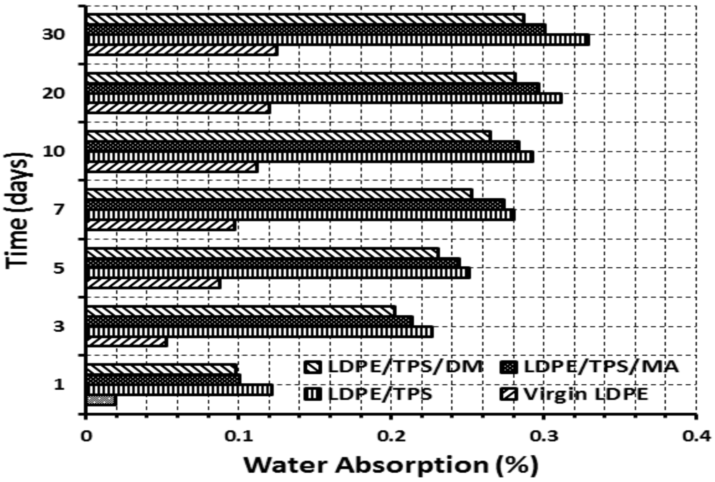


Figure 8 Water uptake values for virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites

Water Absorption Investigation

Figure 8 illustrates water absorption as a function of immersion time for virgin LDPE, LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites after 30 days of immersion. It was noticed that the water absorption rate of LDPE/TPS, LDPE/TPS/MA, and LDPE/TPS/DM composites was higher in the initial 5 days, then regular state saturation occurred. The decrease in water absorption rate throughout the immersion may be due to the concentration gradient on the components. Water molecules can easily fill the composite surfaces and enter the composite through cavities, resulting in more water being absorbed during squatter exposure. Water absorption may drop somewhat as immersion time increases, assome starch particles were removed from the sample. It was suggested that after water uptake, the starch particles swell, increase in size and become compelling. It is observed that LDPE/TPS/DM composites have a lower percentage of water absorption than other composites. Compatibilized LDPE/TPS/DM composites reduce the number of free hydroxyl groups on the surface and reduce the water absorption percentage.

CONCLUSIONS

In this investigation, uncompatibilized and compatibilized composites based on LDPE were discussed with the content of TPS. From the beyond discussion, we can draw the following decisions:

- The MFI value of LDPE/TPS composites with or without compatibilizers decreases with increasing TPS content. LDPE/TPS/DM composites have been shown to have higher MFI than LDPE/TPS and LDPE/TPS/MA composites.
- As the amount of TPS increases, the tensile modulus, flexible strength, and modulus of the uncompatibilized composites begin to increase, but the tensile strength and impact strength gradually decrease. The addition of compatibilizers further enhances the mechanical properties of the composite.
- SEM micrographs prove that the LDPE/TPS/DM composite can form a bond between TPS and LDPE and that the starch particles are evenly dispersed in the polymer matrix.
- Since the thermal degradation temperature and thermal stability of LDPE/TPS/DM composites have also been improved, the results of DSC have shown the compatibility of the components of the composite system.
- Studies of water absorption have shown that in LDPE/TPS/DM composites and extraction of water in the soil environment, the compatibilized composite shows a lower biodegradation rate than the uncompatibilized one.

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